AD

AD 722952

TECHNICAL REPORT

WVT-7106

THE ELEVATED TEMPERATURE PROPERTIES OF TWO 81MM MORTAR TUBE ALLOYS 4337M AND 4140

BY

RICHARD S. DE FRIES

JUNE 1971

BENET R&E LABORATORIES

WATERVLIET ARSENAL

WATERVLIET—NEW YORK

AMCMS No. 4410.16.0008

57

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Watervliet Arsenal Watervliet, N.Y. 12189	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

THE ELEVATED TEMPERATURE PROPERTIES OF TWO 81MM MORTAR TUBE ALLOYS 4337M and 4140

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5. AUTHOR(S) (First name, middle initial, last name)

Richard S. DeFries

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1971	55	8

8a. CONTRACT OR GRANT NO. AMCMS No. 4410.16.0008	9a. ORIGINATOR'S REPORT NUMBER(S) WVT-7106
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Weapons Command

13. ABSTRACT

An evaluation was made of the effect of room and elevated temperatures (800 to 1200°F) and times at these temperatures (0 to 30 hours) on the mechanical properties of two mortar tube alloys, AISI 4140 and AISI 4337 modified, quenched and tempered to four strength levels. The elevated temperature yield strength and ductility after exposure to the various temperatures for various times are discussed. The room temperature yield strength and -40°F impact energy after exposure to various temperatures for various times are also discussed. Results of the elevated temperature tensile testing of the two alloys showed that the yield strength decreases rapidly with high temperatures. The ductility (%RA) increases with increasing temperature and remains fairly constant with time at temperature. The room temperature yield strength decreases with time after exposure at temperatures above the tempering temperature of the alloy. The -40°F Charpy V-notch impact strength increases after exposure at temperatures higher than the tempering temperature of the alloy. Increasing the room temperature yield strength (by lowering the tempering temperature) does not significantly increase the elevated temperature yield strength of the alloy.

An empirical formula was developed for low alloy steels to calculate the elevated temperature (800 to 1200°F) yield strength from the room temperature yield strength and the operating temperature. This relationship is: $YS_T = 2/3\ YS_{RT} - C(\log T - \log IT)$.

DD FORM 1473, 1 NOV 65 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Elevated Temperatures						
Time at Temperatures						
Mechanical Properties						
Low Alloy Steels						
Ductility						
Impact Strengths						
Formula to calculate elevated temperature yield strengths						

Unclassified
Security Classification

THE ELEVATED TEMPERATURE PROPERTIES
OF TWO 81MM MORTAR TUBE ALLOYS
4337M AND 4140

ABSTRACT

An evaluation was made of the effect of room and elevated temperatures (800 to 1200°F) and times at these temperatures (0 to 30 hours) on the mechanical properties of two mortar tube alloys, AISI 4140 and AISI 4337 modified, quenched and tempered to four strength levels. The elevated temperature yield strength and ductility after exposure to the various temperatures for various times are discussed. The room temperature yield strength and -40°F impact energy after exposure to various temperatures for various times are also discussed. Results of the elevated temperature tensile testing of the two alloys showed that the yield strength decreases rapidly with high temperatures. The ductility (%RA) increases with increasing temperature and remains fairly constant with time at temperature. The room temperature yield strength decreases with time after exposure at temperatures above the tempering temperature of the alloy. The -40°F Charpy V-notch impact strength increases after exposure at temperatures higher than the tempering temperature of the alloy. Increasing the room temperature yield strength (by lowering the tempering temperature) does not

Cross Reference Data

Elevated Temperatures

Time at Temperatures

Mechanical Properties

Low Alloy Steels

Ductility

Impact Strengths

Formula to calculate elevated temperature yield strengths

significantly increase the elevated temperature yield strength of the alloy.

An empirical formula was developed for low alloy steels to calculate the elevated temperature (800 to 1200°F) yield strength from the room temperature yield strength and the operating temperature. This relationship is: $YS_T = 2/3\ YS_{RT} - C(\log T - \log IT)$.

TABLE OF CONTENTS

FIGURES

TABLES

GLOSSARY

AISI	American Iron and Steel Institute
T	Temperature (°F)
IT	Inflection temperature - Temperature at which the yield strength decreases sharply as a function of the test temperature.
0.1 YS	0.1% offset yield strength (ksi)
M	Modified
RA	Reduction in Area (%)
4337M (170)	4337M tempered to a 0.1 YS of approximately 170 ksi
4337M (155)	4337M tempered to a 0.1 YS of approximately 155 ksi
4140 (130)	4140 tempered to a 0.1 YS of approximately 130 ksi
4337M (120)	4337M tempered to a 0.1 YS of approximately 120 ksi
ksi	Kips (1000 pounds) per square inch
UTS	Ultimate tensile strength (ksi)
0.2 YS	0.2% offset yield strength (ksi)
El	Elongation in 2" gage length (%)
C_v	Charpy V-notch impact test (ft. - lbs.)
Rc	Rockwell "C" hardness

INTRODUCTION

During the full charge sustained firing of the 81mm mortar, at which hoop stresses are at a maximum, temperatures as high as 1200°F have been calculated. At these pressures and temperatures, bulging can occur if the hoop stress in the tube exceeds the yield strength of the material. This problem has led to programs to determine the elevated temperature transverse yield strength, after exposure for various lengths of times, of various potential mortar tube materials.[2,3] The present study considers those materials currently used in the M29 and M29E1 barrels.

APPROACH TO THE PROBLEM

Two materials have been used for 81mm mortar barrels, viz., AISI 4140 in the M29 and AISI 4337M in the M29E1 (Table I). These base materials were forged into four and one half inch round bars, i.e., the same size material from which production barrels are made. The bars were cut into one inch thick transverse discs, which were then heat treated to four strength levels, as shown in Table II. Standard .357 inch diameter tensile bars and standard Charpy V-notch impact bars were machined from each disc, as shown in Figure 1. From these, the following data were obtained:

1. Room temperature tensile data and Charpy V-notch impact data at -40°F for each material.

2. Elevated temperature tensile data at 800, 900, 1000, 1100, and 1200°F after exposures of from five minutes to 30 hours for each strength level material.

3. Room temperature hardness data after exposure to the conditions cited in 2. From these data, the room temperature yield strength was

estimated, based on data shown in references 4 and 5 (Figure 2). This figure also shows data generated in this study which corroborates the data from the references.

4. Charpy V-notch impact data at -40°F after exposures to the elevated temperatures for one to thirty hours for all material except 4337M (120).

The elevated temperature tensile testing was conducted according to ASTM E21-66T*. For the five to sixty minute exposure tests, all the heating was done in a furnace on the testing machine. The calibrated furnace requires about an hour to heat the specimen from room temperature to the testing temperature, and five minutes is the minimum exposure time available for equalization of the temperature within the test specimen. At exposure times less that the five minutes, the yield strength is somewhere between that at the five minute exposure and the room temperature yield strength. For the longer exposure time tests, the specimens were first heated in a heat treating furnace, cooled to room temperature and then tested in the tensile machine after an additional 15 minutes at the required temperature. A strain rate of .005 in/in/min. was used for all tests. The Charpy V-notch bars were tested in a standard calibrated machine after the specimens had been held for at least 15 minutes in dry ice and alcohol at -40°F.

RESULTS

All the data generated are shown in Tables III-VI for 4140 (130), 4337M ((170), 4337M (155) and 4337M (120) respectively. For ease of interpretation and to note the various trends, the data were plotted as a function of the several parameters investigated. Specifically, Figures 3-14 show the following:

* Tentative recommended practice for short-time elevated temperature tension test of materials.

Figure 3 - Effect of tempering temperature on room temperature yield strength and RA and on -40°F C_V impact energy.

Figures 4-7 - Effect of exposure time on the elevated temperature yield strength.

Figure 8 - Summation of the effects of elevated temperature on yield strength.

Figures 9-11 - Effect of exposure time and temperature on the resultant room temperature yield strength as estimated from the R_c hardness for 4140 (130), 4337M (170) and 4337M (155).

Figures 12-14 - Effect of exposure time and temperature on the resultant -40°F C_V impact energy for 4140 (130), 4337M (170) and 4337M (155).

DISCUSSION OF RESULTS

Elevated Temperature Yield Strength

In previous hot tensile testing,[1-3], it was determined that the elevated temperature yield strength of high strength steels decreases rapidly with temperature and only slightly with time at temperature. The same trend was seen for these materials as shown in Figures 4-7. In every case, the strength dropped after the first five minutes exposure followed by either no change or a relatively small change with additional exposure time. This observation suggests that future evaluation of the elevated temperature tensile properties of low alloy steels for mortar tube use need consider only short time exposure. In several cases, there appeared to be a slight increase in strength with long time exposure. This might be attributed to a secondary hardening phenomena associated with precipitation of alloy carbides. However, because the change was slight, no attempt was made to verify this possibility.

Again, as seen before, the parameter which exerts the greatest control over the elevated temperature yield strength was exposure temperature (Figure 8). In plotting this curve, the yield strength after five minutes exposure was used. Several points can be made concerning Figure 8. First, it is seen that the data tend to converge at the higher temperatures regardless of the starting strength. Second, the most important parameter controlling the yield strength at any given temperature up to the point of convergence, is the initial yield strength of the material.

The data for yield strength at temperature appears to fit the following general relation:

$$YS_T = \frac{2}{3} YS_{RT} - f(T, YS_{RT})$$

The general form for $f(T, YS_{RT})$ is not certain but for the low alloy steels and the maraging steel tested in this and other studies[3] might be expressed as:

$$f(T, YS_{RT}) = C(\log T - \log IT)$$

or specifically

$$YS_T = \frac{2}{3} YS_{RT} - C(\log T - \log IT)$$

where T = Test temperature in °F

IT = Inflection temperature in °F

and C = Empirical material constant

The inflection temperature is based on the observation of a change in slope of the yield strength vs. test temperature curves. Therefore, its measurement is not precise, but might be defined as that temperature at which the yield strength drops to two-thirds of its original room temperature value. Using an IT of 800°F, and $C = \frac{T(YS_{RT})}{400°F}$ the yield strength at several elevated

temperatures for several of the materials tested was computed (Table VII). It is seen that they compare favorably with the actual data.

While in its present state, this relation is purely empirical, it has several potential benefits to commend it. If the concept were accurate, it might be possible to define the inflection temperature more precisely based on its coincidence with some metallurgical occurrence in the steel. The heating of the material prior to testing is essentially a tempering operation. This subject has been studied in great detail so that the microstructural changes which occur are fairly well understood. It is known, for example, that certain alloy additions such as Cr, reduce a steel's temperability by forming a stable carbide, thereby maintaining hardness and strength to higher tempering temperatures and, if present in sufficient quantities, causing secondary hardening. These steels should then have a higher IT. It was observed, in fact, that on the materials tested, those alloys with the greater amount of carbide formers did maintain their strength to a higher temperature and showed a higher IT.

If a relation could be reliably shown, it would be very useful in predicting the actual strength at elevated temperature for any alloy with a minimum of testing. Consider that the yield strength-test temperature data were available for an alloy steel with a specific room temperature yield strength. Then the effect on elevated temperature strength could be calculated from the room temperature data. To allow this, more information is required regarding the factors which control the several parts of the relation. While it has been suggested that carbide formers should show a higher IT, the precise effect of the addition of each alloy might be determined. A relation showing the effect of alloying addition and tempering temperature on room temperature hardness

has been derived [5,6]. This type of relation might be examined for use here.

At this time, the effect of initial yield strength on C and IT is unknown. It is probable that there should be an effect. Since the R.T. yield strength is changed by varying the tempering temperature, and since heating during testing (or during firing) is equivalent to tempering, it should be expected that the higher yield strength materials should show the effects of heating at lower temperatures than the lower strength materials. However, it should also be expected that the elevated temperature yield strengths should converge at some high temperature, in excess of the original tempering temperature. The rationale for this is simple. During tempering, carbides are precipitated and the microstructure tends toward its equilibrium state of ferrite and carbide. If the temperature is high enough, the microstructures will be the same, irrespective of the initial state of the material. That the data do tend to converge is seen in the data shown in Figure 8.

One of the most interesting phenomena observed was the initial drop in yield strength with short exposure times (five minutes) followed by little decrease in strength with additional time. This cannot be explained strictly in terms of changes in microstructure with additional tempering. Two specific observations tend to corroborate this. First, since the precipitation of carbide is diffusion controlled, time is an important factor. It is improbable that five minutes is sufficiently long to cause any significant change in microstructure. Second, the drop in strength is seen at temperatures below the initial tempering temperature. Again, significant changes in microstructure would be unexpected.

Probably, the sudden large drop in yield strength is related to an effect

on the mobility of dislocations which are responsible for plastic deformation. The dislocations become more mobile, deformation becomes easier and yield strength is decreased. It is known that increasing temperature increases the ease with which the dislocations move and so explains the effects seen. It would be naive to attempt to quantitize this since the interrelations of dislocations and microstructure in steel is a subject for which there is no simple explanation. However, the effect of the carbide formers on reducing temperability is likely due to the carbide's interference with the movement of the dislocation and increasing the yield strength.

In summarizing the effects of temperature on yield strength, the following appear factual:

1. The yield strength drops gradually with exposure to temperatures to a characteristic strength of 2/3 its room temperature value.

2. Beyond the Inflection Temperature, the effect of temperature becomes more pronounced.

3. At a sufficiently high temperature, the initial yield strength becomes incidental and unimportant. However, until that temperature is reached, the initial yield strength controls the elevated temperature yield strength.

In addition, there are several trends and hypothese shown below which while not proven by the data, appear reasonable and worthy of further study. This is suggested since the generation of elevated temperature yield strength data for a new alloy or strength condition is costly and time consuming. It would be desirable if a relation were available to preclude the necessity for such large scale testing.

1. The sudden drop in yield strength is probably due to an increased

mobility of dislocations with an insignificant effect of change in microstructure.

2. Carbide formers should delay the IT.

3. Material with higher yield strengths should show either a lower IT or a higher C.

4. The value of IT may be constant for a particular alloy system.

5. The values of C and IT may be sufficiently similar for the mass of low alloy steels with low percentages of carbide formers that they can be considered as one.

Room Temperature Yield Strength

The effect of various exposure conditions on the room temperature strength was approximated from the hardness of the tensile test bars after elevated temperature testing. While not so desirable as actual tensile testing, this was considered sufficiently valid based on data taken from the literature (Figure 2) on the relation of YS to Rc hardness and data obtained in the initial stages of this program. The data for each condition plotted vs. exposure time are shown in Figures 9 - 11. It is seen that in most cases there is no effect of exposure below the initial tempering temperature even after 30 hours exposure. Generally, in calculating the hardness after tempering, the effect of time is introduced as a logarithmic function, so that large changes in time are required to effect noticeable changes in strength. In all cases, the temperature is much more important. Again, exposure to elevated temperature, whether during firing or in a heat treat furnace, is simply a tempering operation.

Ductility

In all cases, the ductility, viz., RA, followed the rules generally seen, viz., as the yield strength decreased, the ductility increased. It was seen that as the temperature of exposure increased, the ductility increased markedly. Again, as with the yield strength, increased time at temperature had no effect.

Impact Energy

Since one of the basic criteria for acceptance of cannon tube materials is the C_V impact energy at -40°F, this property was evaluated for all the materials except 4337M (120) which was subjected only to the tensile testing. As with the room temperature tensile data, the C_V impact data simply represent effects of tempering. As the exposure temperature increased, the impact energy increased.

While the elevated temperature data showed a temdency for yield strength convergence at the higher temperatures, no similar trend was noted in the low temperature impact data after exposure to the high temperatures. For example, whereas the yield strengths of all materials tested were similar when exposed at 1200°F, the -40°F impact energy of 4337M was double that of the 4140. This is the same trend that has been reported in the literature previously[8], namely, that different alloy steels may show the same strength but significantly different impact energy.

Application to Mortar Tubes

As noted in the introduction, one of the problems associated with mortar tube materials is the possibility for bulging, particularly during maximum-charge rapid or sustained firing. By considering the mechanical property data

generated, it is possible to select an <u>initial</u> yield strength to withstand a given hoop stress. The decision is dependent on the assumed or desired starting conditions.

Based on an applied hoop stress of 86 ksi, it is seen that 4140 (130) is inadequate above approximately 800°F. By a similar analysis, the 4337M (150) material is adequate to approximately 1000°F for this hoop stress.

While the yield strength data suggest that either 4140 or 4340M would suffice if heat treated to the same initial yield strength, the Charpy data separate them markedly. For a given strength, the C_V (-40°F) of the 4337M is higher than that for the 4140. To separate the material even farther, it is seen that for an applied hoop stress of 86 ksi, the best material tested was 4337M (155) since it exhibited the same high temperature tolerance as the 4337M (170) with a higher C_V (-40°F) impact energy.

One danger inherent in the application of high temperature tensile data is the possible effect of strain rate on yield strength. Generally, the yield strength increases with strain rate. Then, since the loading rate during firing is considerably higher than that during tensile testing, it is possible that bulging would not occur as predicted by these data. However, the use of these data is conservative and should preclude any bulging problems.

CONCLUSION

The following conclusions are based on the data presented:

1. The elevated temperature transverse yield strength of 4140 and 4337M, decreases rapidly with temperature from 800 to 1200°F.

2. Exposure times to 30 hours at elevated temperatures had little or no effect on the hot transverse yield strength after a sharp decrease from

room temperature strength within the first five minutes of exposure.

3. The sustained firing rate which each material can withstand depends on the hoop stress and charge used. Generally, however, as the initial yield strength of the material increases, the tolerable firing rate increases.

4. The elevated temperature yield strengths converge at high temperatures so that if the working temperature is sufficiently high, the starting yield strength is irrelevant. For the materials tested, this occurred at approximately 1000°F.

5. The room temperature yield strength based on hardness, decreases with exposure temperature, indicating a simple tempering effect.

6. The data suggest that the elevated temperature strength is primarily a function of initial yield strength so that different alloy steels heat treated to the same strength should perform similarly. The materials are separable based on impact data.

7. The elevated temperature yield strength data for the alloys tested appear to follow the relation

$$YS_T = \frac{2}{3} YS_{RT} - f(YS_{RT}\ T)$$

8. For a hoop stress of 86 ksi, the best material to use based on these tests is 4337M (155).

FUTURE WORK

1. To resolve the accuracy of the empirical relation described in this report, those trends and hypotheses suggested but unproven should be investigated. This involves an alloy development study with a strong emphasis on the physical metallurgical characteristics of the materials. As noted

previously, the success of such a study could decrease markedly the amount of elevated temperature testing needed to characterize an alloy, and permit the more logical selection of a material for high temperature applications.

2. Additional data should be gathered on the study suggested above and on those alloys already tested.

ACKNOWLEDGMENT

The elevated temperature tensile testing conducted by General Electric Co., M&P Laboratory, is gratefully acknowledged.

REFERENCES

1. Simmons and Cross, ASTM Special Publications No. 199.

2. DeFries, R.S., "Evaluation of Elevated Temperature Materials for the 81MM Mortar Tube", Watervliet Arsenal Report No. 6629, Nov. 1966, and ASM Metal Progress Vol. 92, No. 6, Dec. 1967.

3. Heiser, F.A., "Effect of Exposure to Elevated Temperature on the Mechanical Properties of Maraging Steel", Watervliet Arsenal Report No. 6712, June 1967.

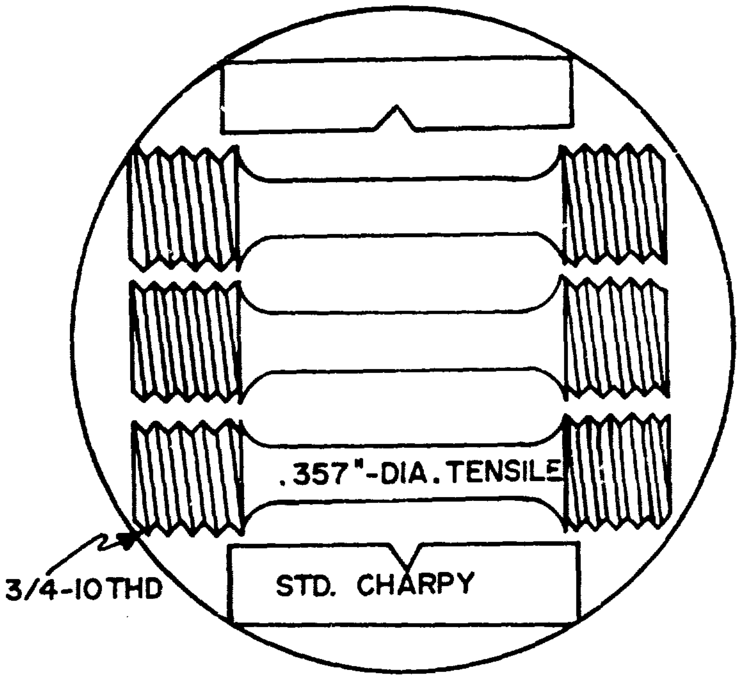
4. ASM Metals Progress, Mechanical Properties in Relation to Hardness.

5. Lubahn, "Yield Strength vs. Hardness".

6. ASM Metals Handbook, Vol. 1, 8th Edition, "Properties of Steel at Elevated Temperatures".

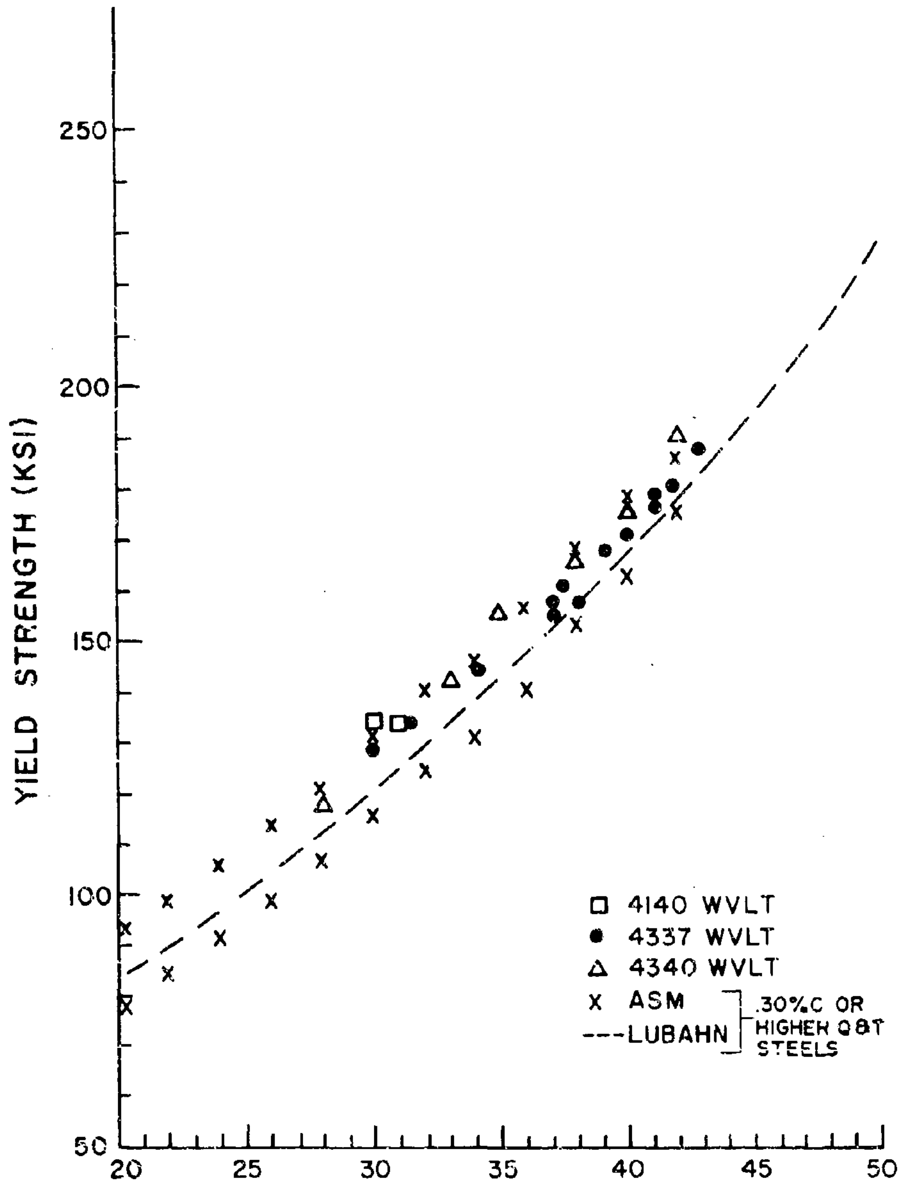
7. Hollomon, J.H., Jaffe, L.D., "Ferrous Metallurgical Design", Wiley and Sons, Inc., 1947.

8. Bullens, D.K., "Steel and its Heat Treatment", Wiley and Sons, Inc., 1949.



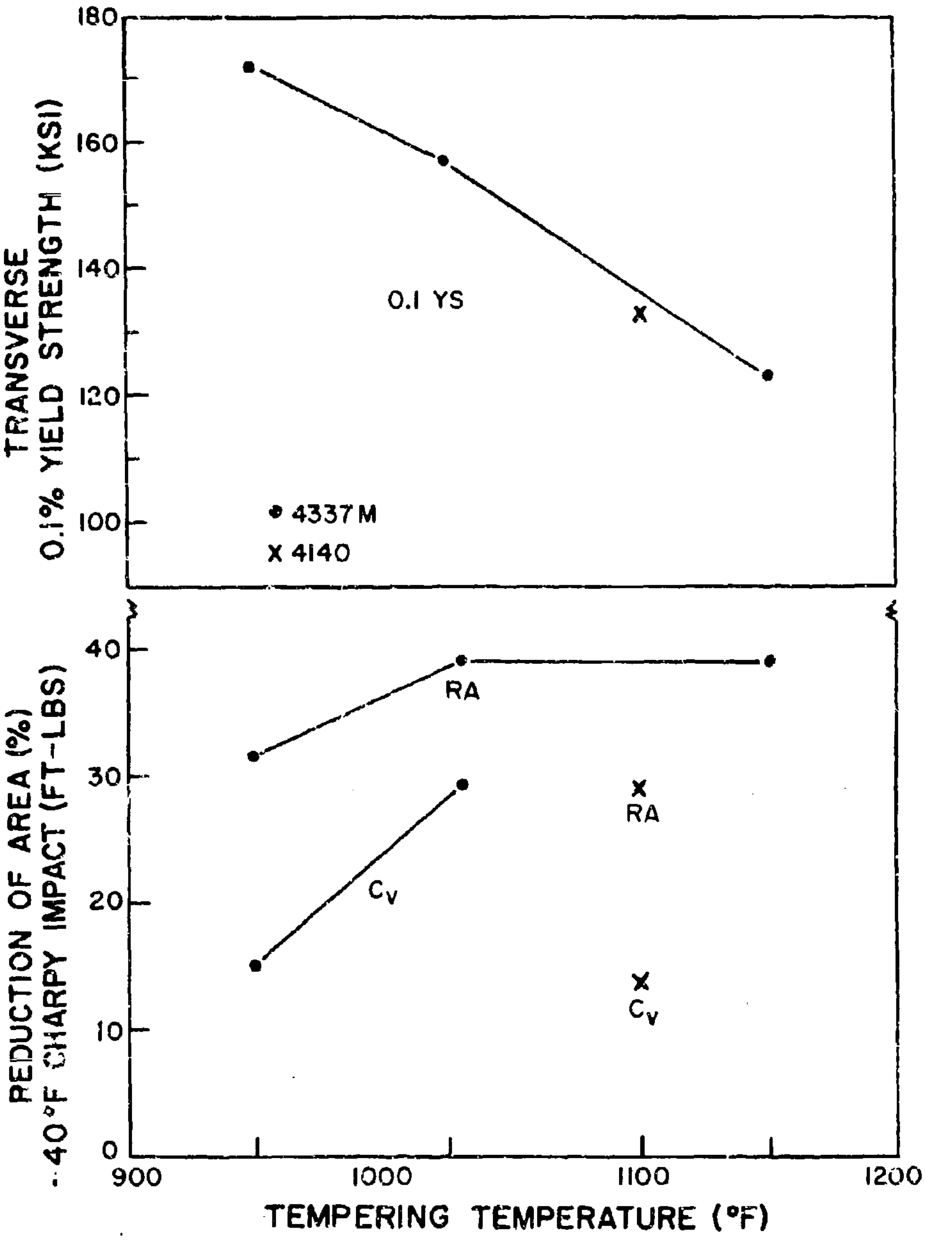
TENSILE AND CHARPY BARS

FIG. 1



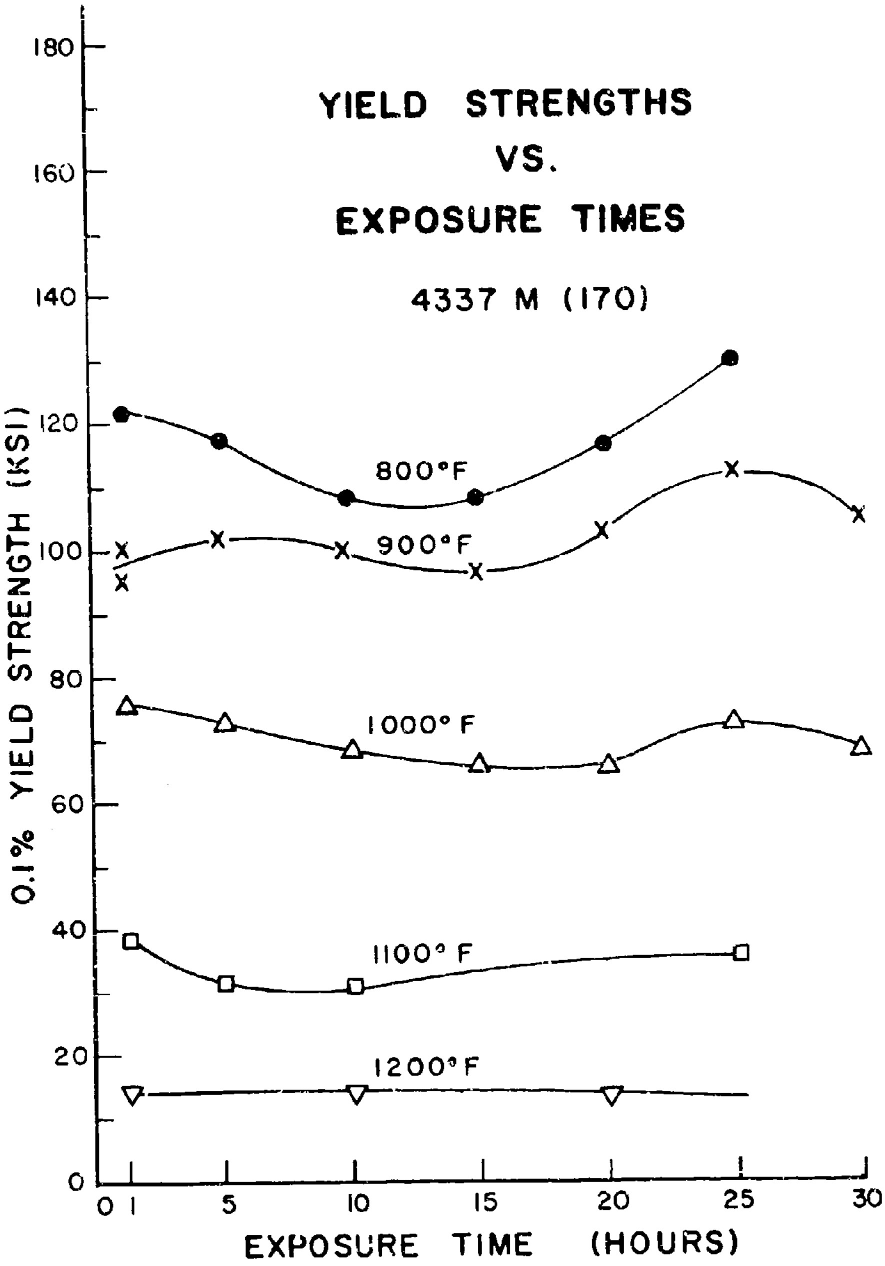
YIELD STRENGTH VS. HARDNESS

FIG. 2



TRANSVERSE
0.1% YIELD STRENGTH (KSI)
180
160
140
120
100
0.1 YS
4337 M
X 4140
REDUCTION OF AREA (%)
-40°F CHARPY IMPACT (FT-LBS)
40
30
20
10
0
RA
RA
C_V
C_V
900
1000
1100
1200
TEMPERING TEMPERATURE (°F)

FIG. 3



YIELD STRENGTHS
VS.
EXPOSURE TIMES
4337 M (170)
0.1% YIELD STRENGTH (KSI)
180
160
140
120
100
80
60
40
20
0
800°F
900°F
1000° F
1100° F
1200°F
0 1
5
10
15
20
25
30
EXPOSURE TIME (HOURS)

FIG. 4

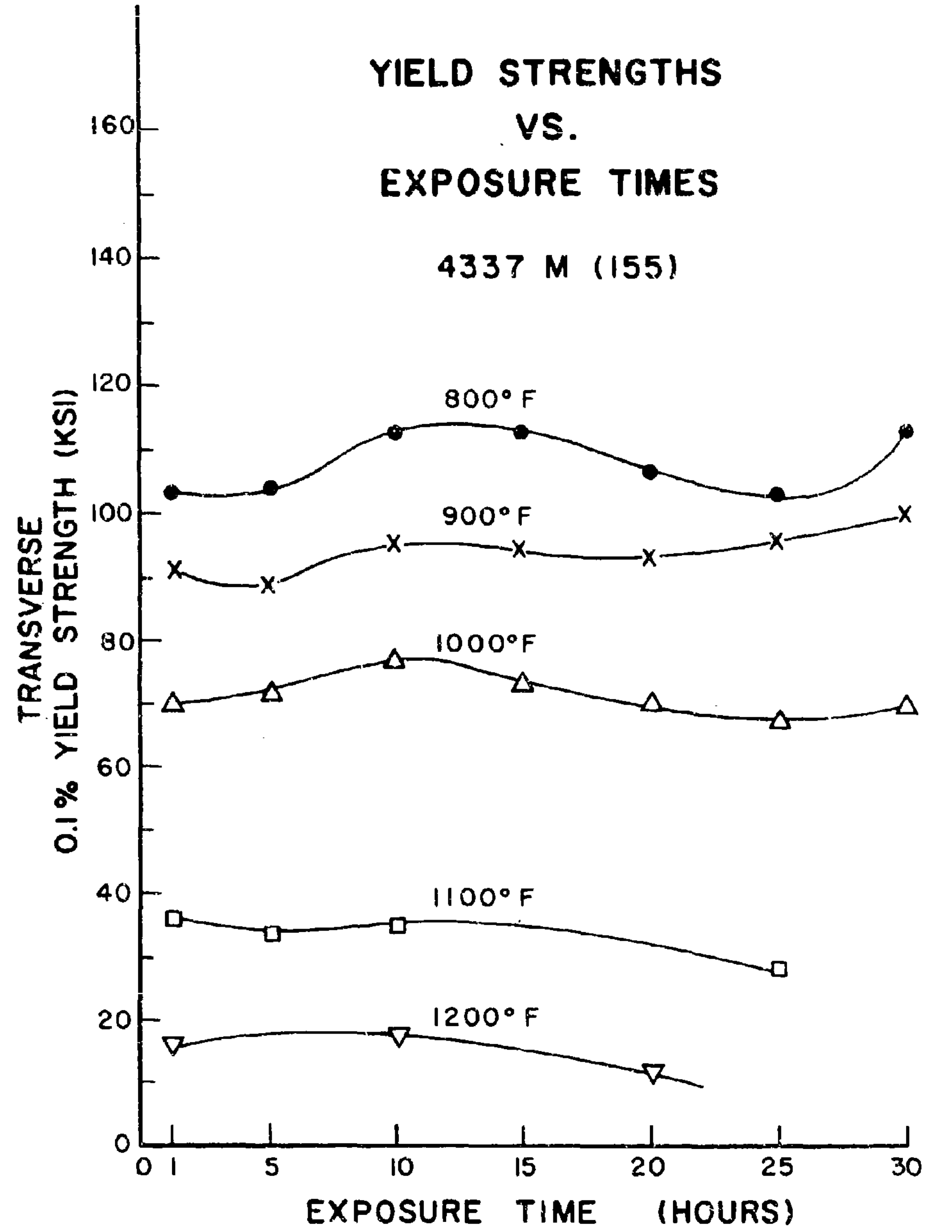

YIELD STRENGTHS
VS.
EXPOSURE TIMES
4337 M (155)
TRANSVERSE
0.1% YIELD STRENGTH (KSI)
EXPOSURE TIME (HOURS)
800° F
900° F
1000°F
1100° F
1200° F
0
20
40
60
80
100
120
140
160
0 1 5 10 15 20 25 30

FIG.5

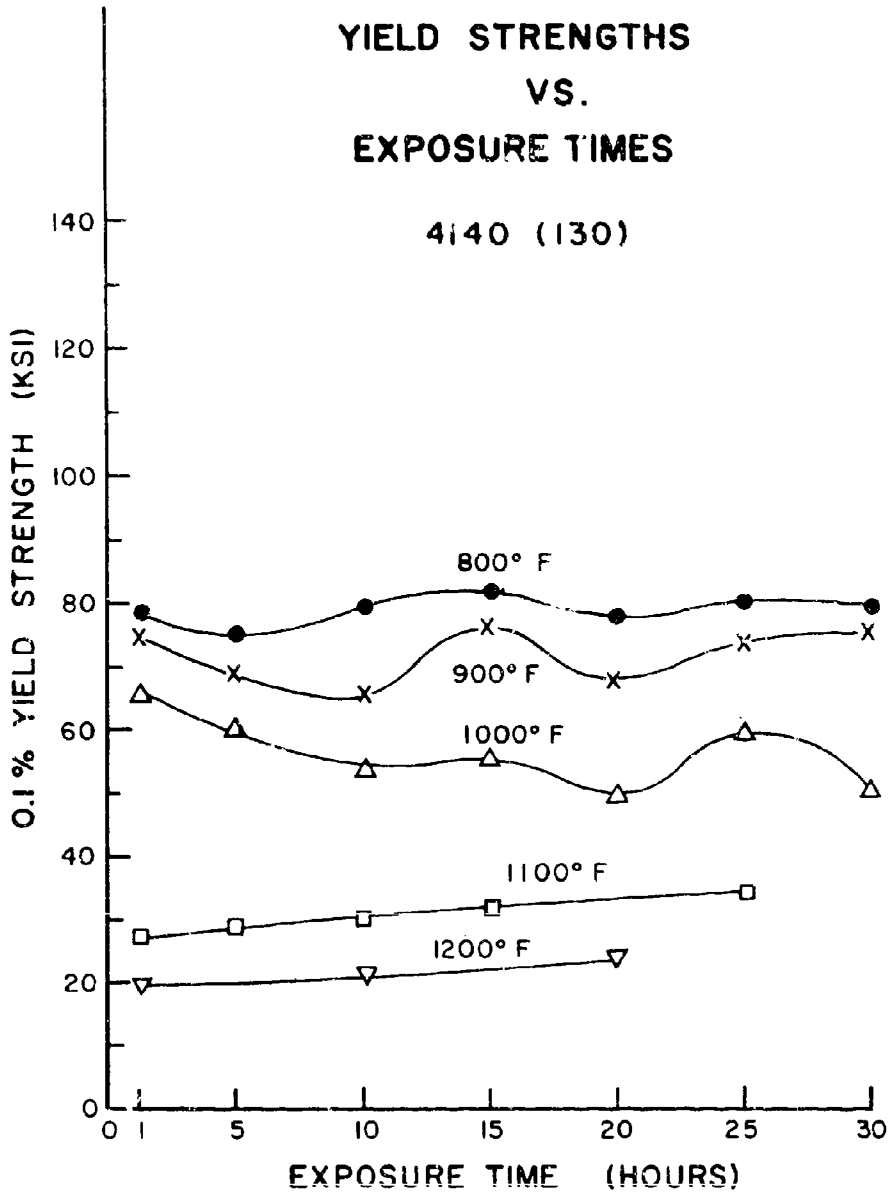

YIELD STRENGTHS
VS.
EXPOSURE TIMES
4140 (130)
0.1 % YIELD STRENGTH (KSI)
140
120
100
80
60
40
20
0
800° F
900° F
1000° F
1100° F
1200° F
0
1
5
10
15
20
25
30
EXPOSURE TIME (HOURS)

FIG. 6

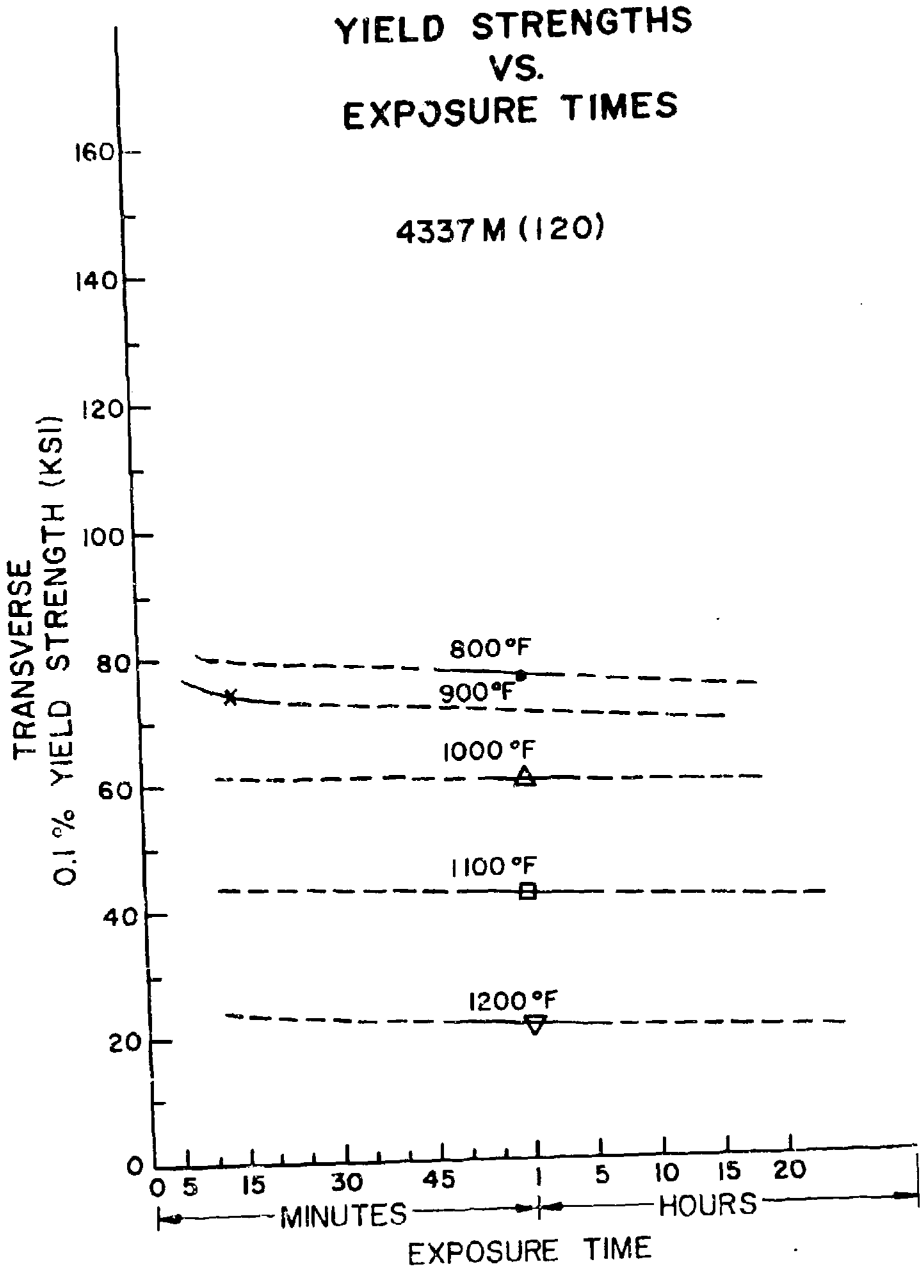
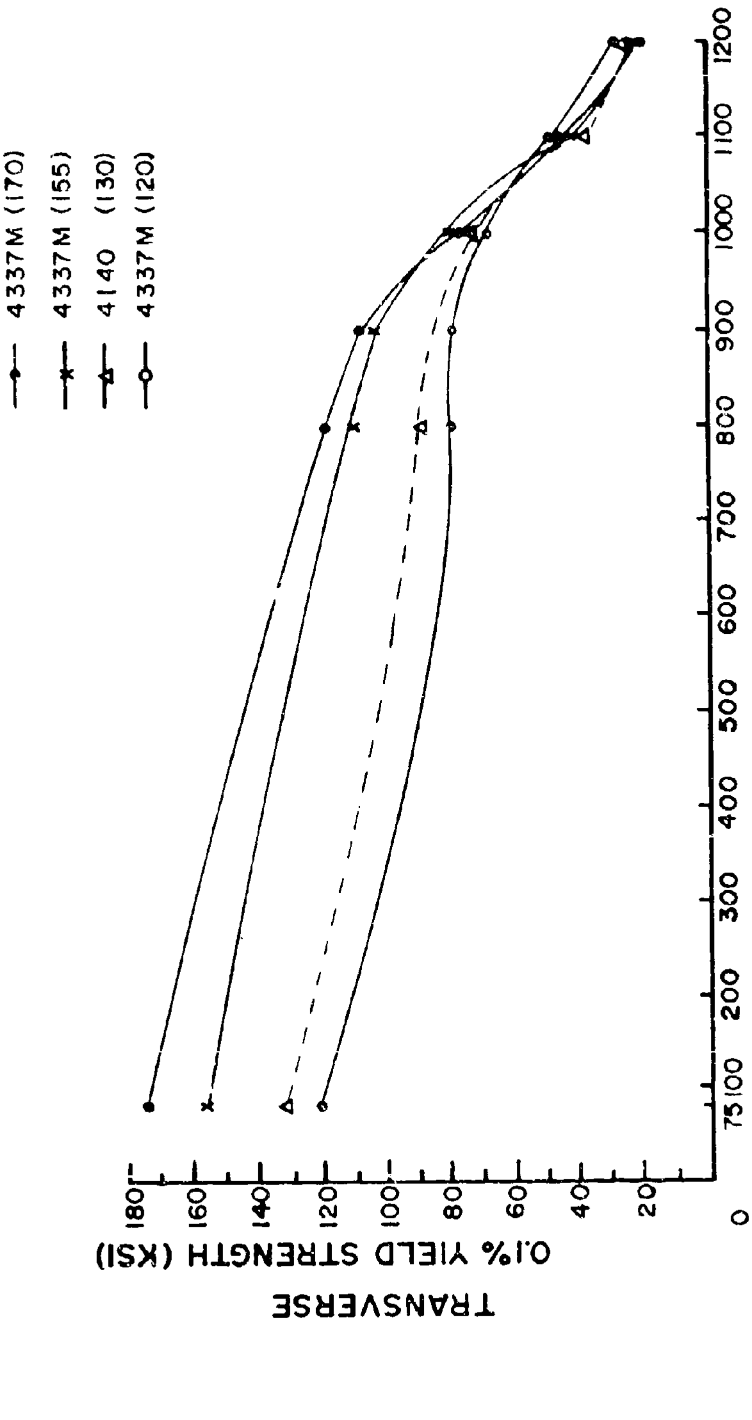
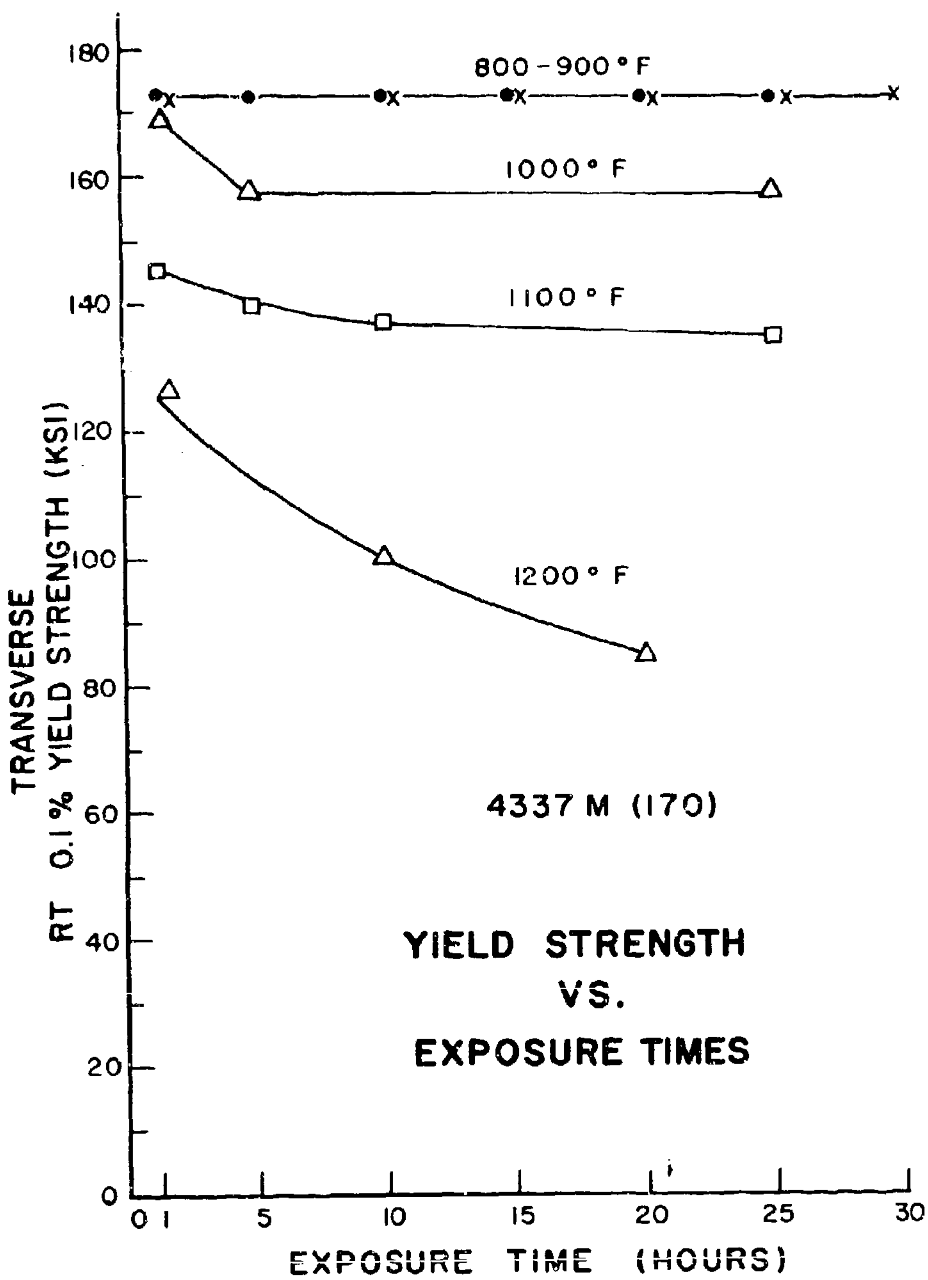

YIELD STRENGTHS
VS.
EXPOSURE TIMES
4337 M (120)
TRANSVERSE
0.1 % YIELD STRENGTH (KSI)
160
140
120
100
80
60
40
20
0
800 °F
900 °F
1000 °F
1100 °F
1200 °F
0 5 15 30 45 1 5 10 15 20
MINUTES
HOURS
EXPOSURE TIME

FIG. 7



YIELD STRENGTH VS. TEST TEMPERATURE

FIG. 8



800 - 900 °F
1000° F
1100° F
1200° F
4337 M (170)
YIELD STRENGTH
VS.
EXPOSURE TIMES
TRANSVERSE
RT 0.1% YIELD STRENGTH (KSI)
EXPOSURE TIME (HOURS)

FIG. 9

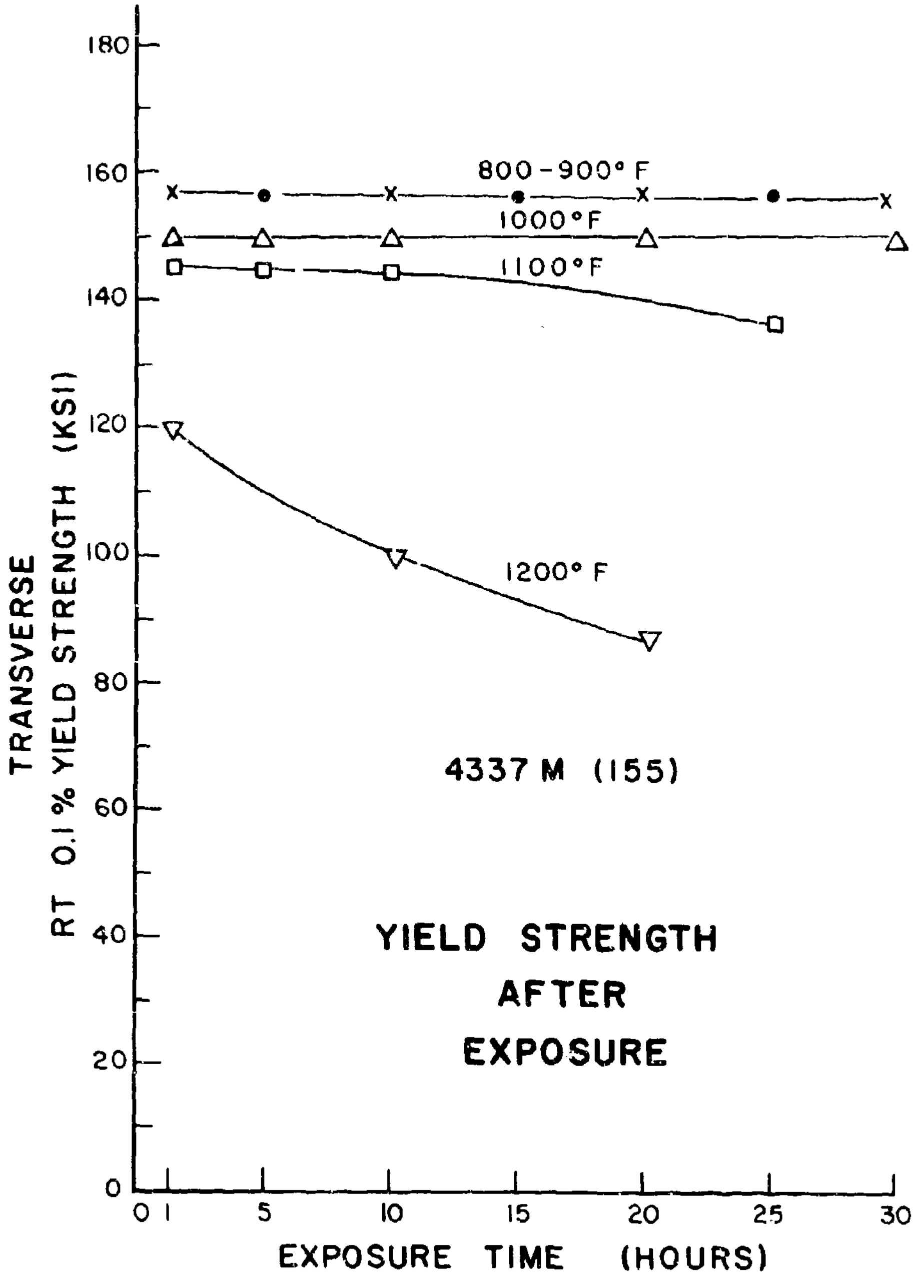

180
160
140
120
100
80
60
40
20
0
TRANSVERSE
RT 0.1 % YIELD STRENGTH (KSI)
800-900° F
1000°F
1100°F
1200° F
4337 M (155)
YIELD STRENGTH
AFTER
EXPOSURE
0 1
5
10
15
20
25
30
EXPOSURE TIME (HOURS)

FIG. 10

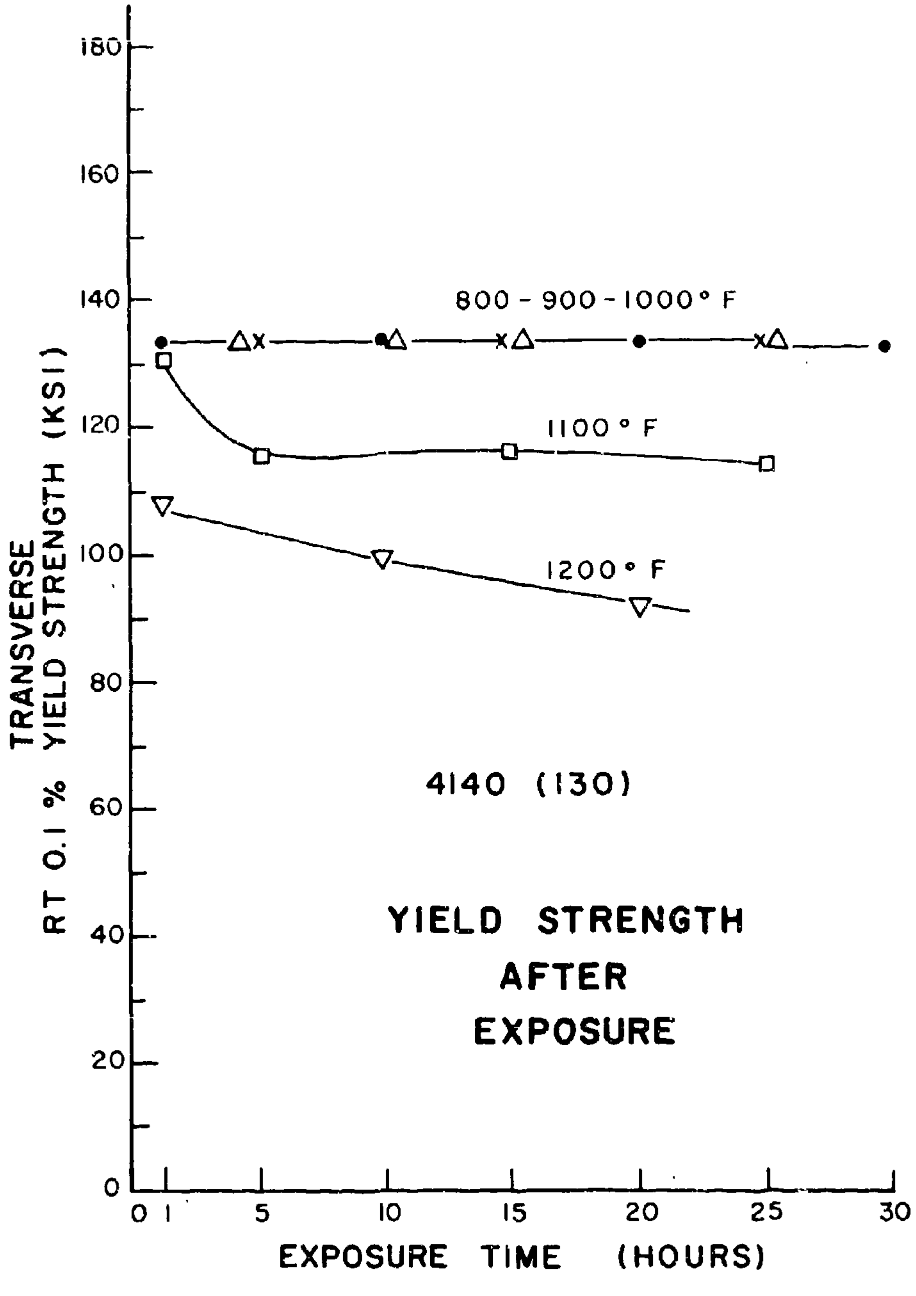

RT 0.1 % YIELD STRENGTH (KSI)
TRANSVERSE
180
160
140
120
100
80
60
40
20
0
800 - 900 - 1000° F
1100° F
1200° F
4140 (130)
YIELD STRENGTH
AFTER
EXPOSURE
0 1
5
10
15
20
25
30
EXPOSURE TIME (HOURS)

FIG. 11

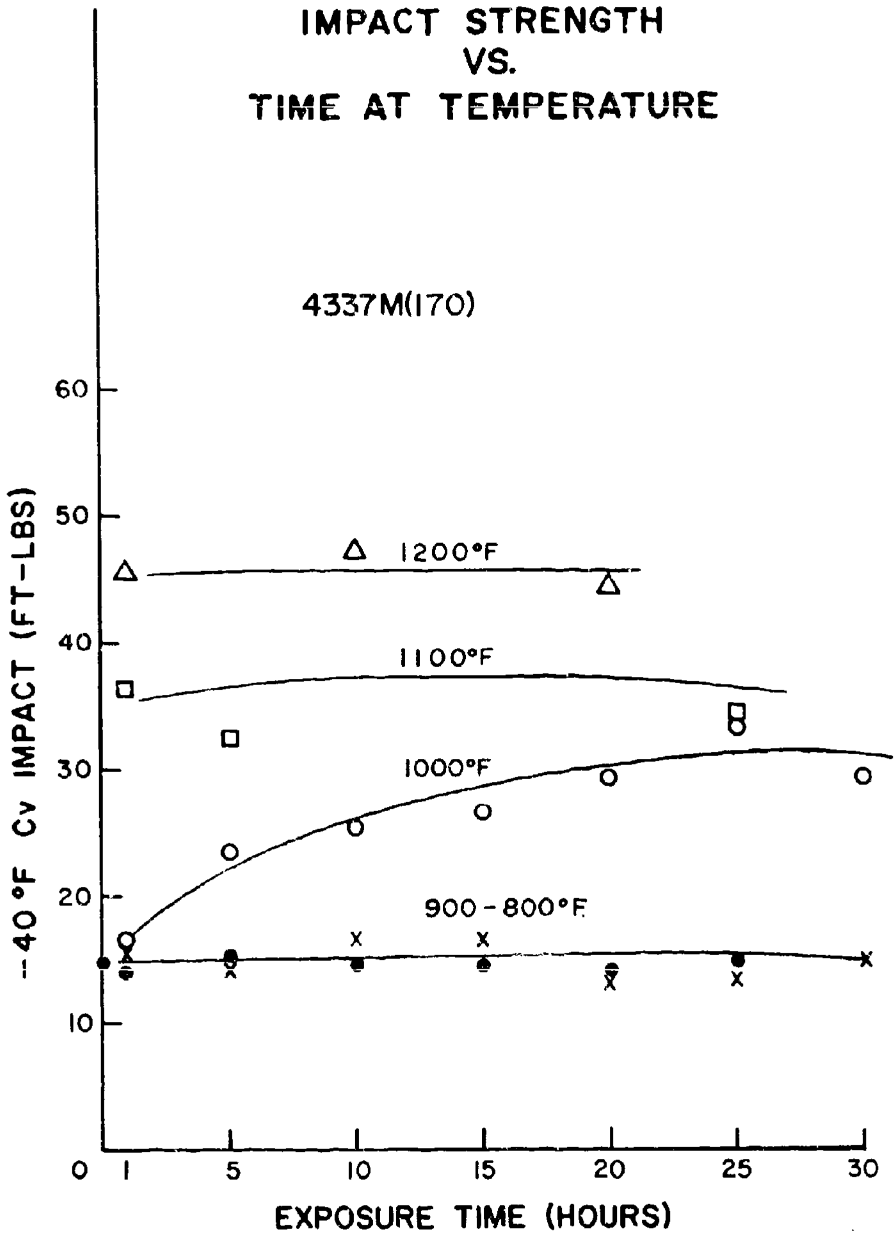

IMPACT STRENGTH
VS.
TIME AT TEMPERATURE
4337M(170)
1200°F
1100°F
1000°F
900-800°F
-40°F Cv IMPACT (FT-LBS)
60
50
40
30
20
10
0
1
5
10
15
20
25
30
EXPOSURE TIME (HOURS)

FIG. 12

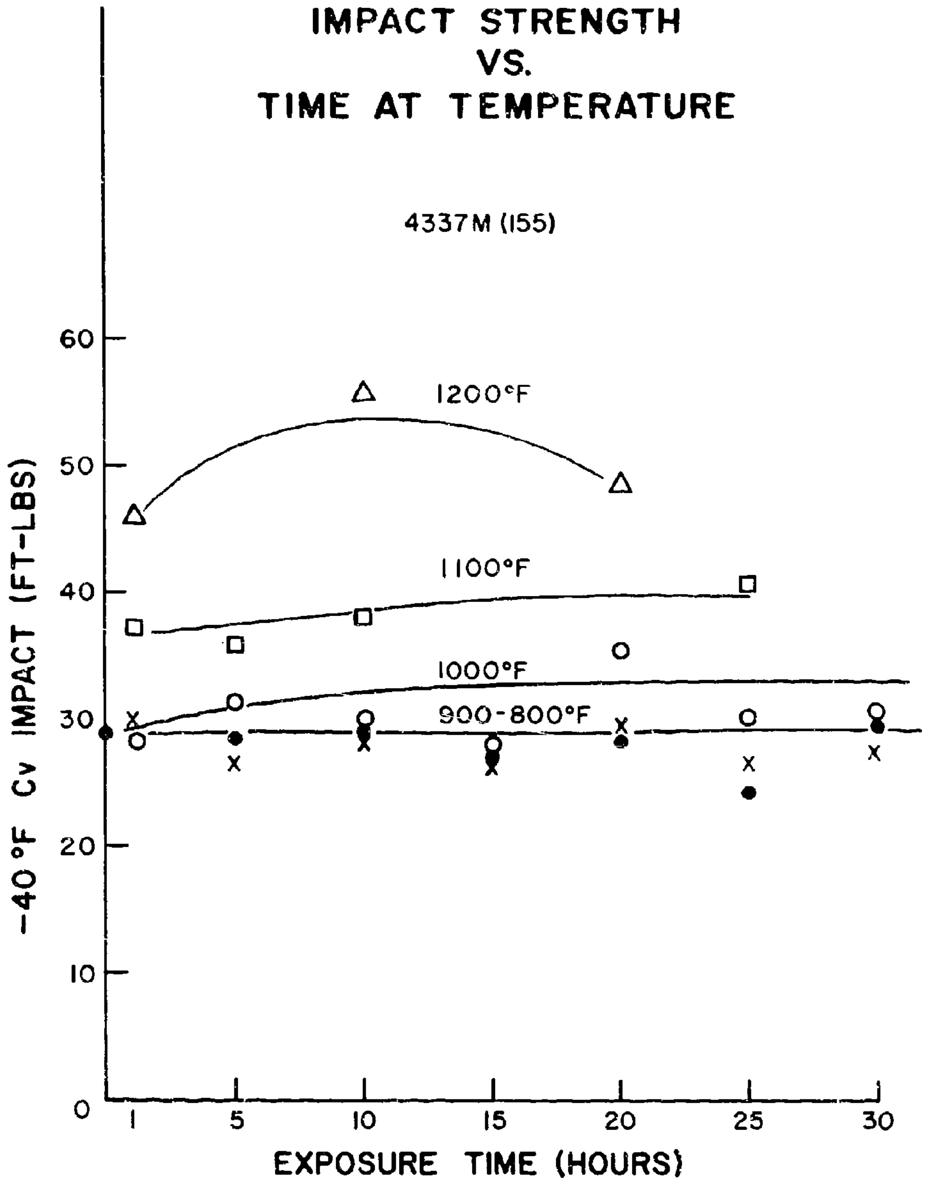
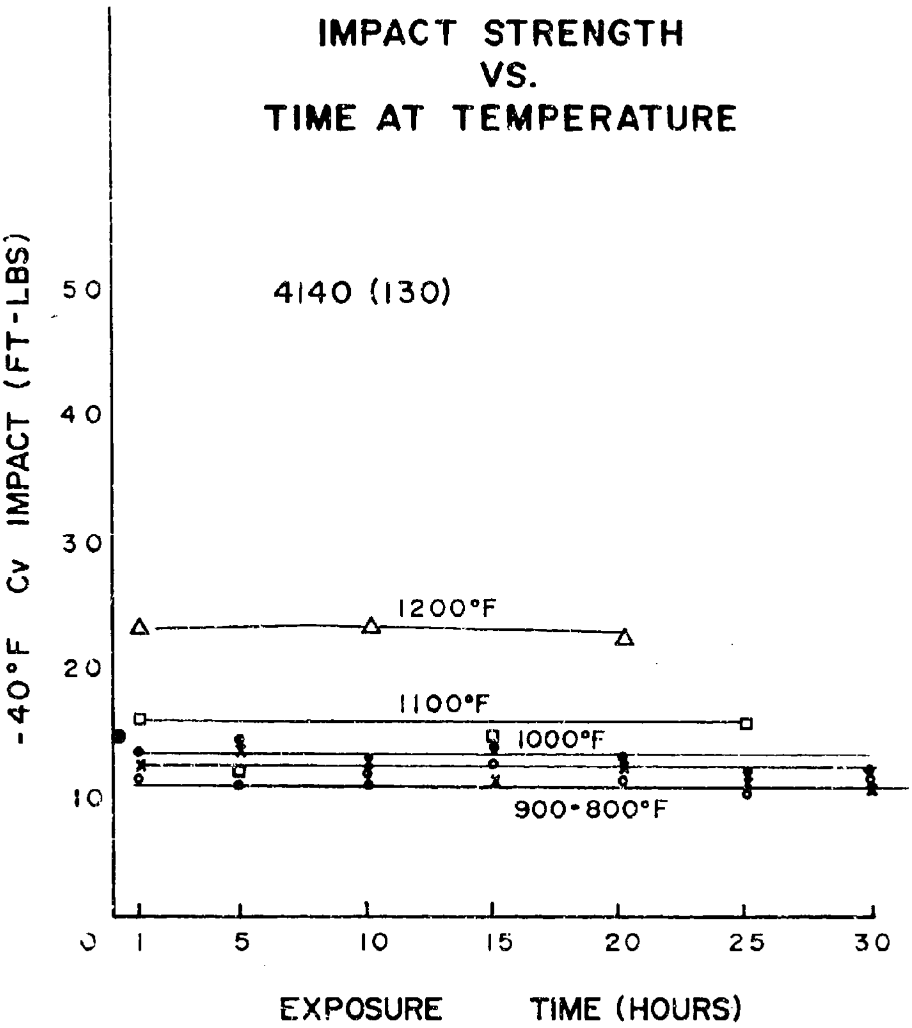
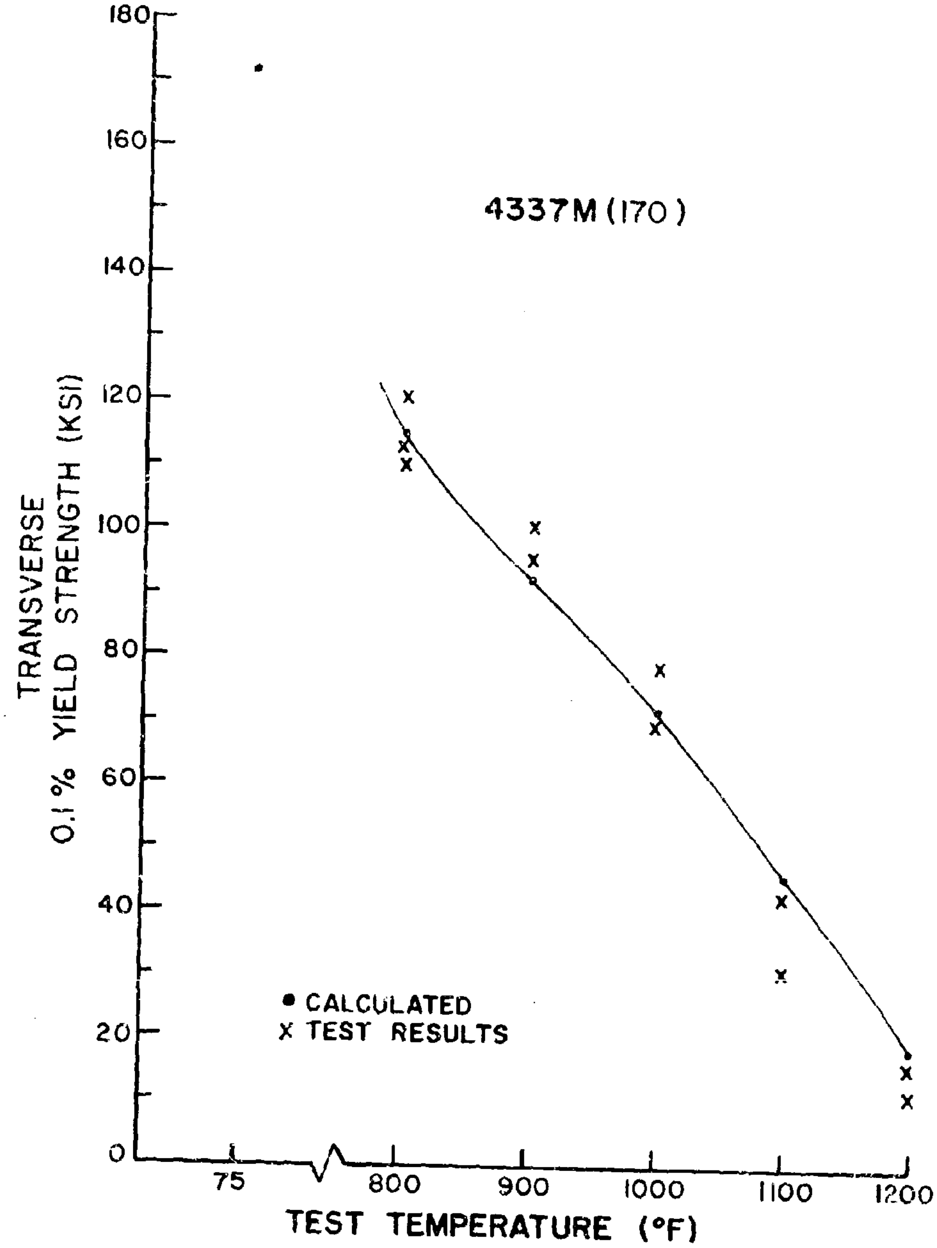

IMPACT STRENGTH
VS.
TIME AT TEMPERATURE
4337M (155)
1200°F
1100°F
1000°F
900-800°F
-40 °F Cv IMPACT (FT-LBS)
0
10
20
30
40
50
60
1
5
10
15
20
25
30
EXPOSURE TIME (HOURS)

FIG. 13



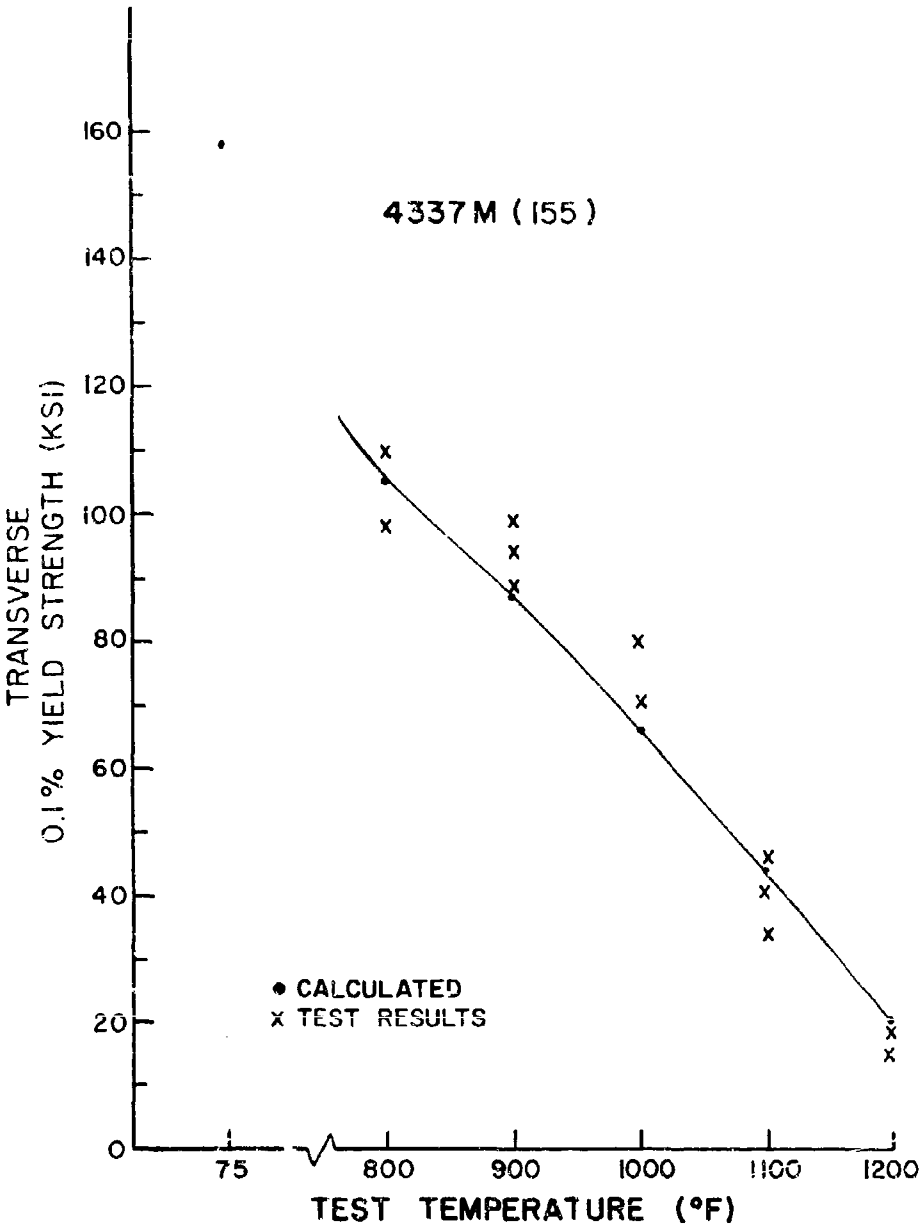
IMPACT STRENGTH
VS.
TIME AT TEMPERATURE
4140 (130)
-40°F Cv IMPACT (FT-LBS)
50
40
30
20
10
1200°F
1100°F
1000°F
900-800°F
0
1
5
10
15
20
25
30
EXPOSURE TIME (HOURS)

FIG. 14



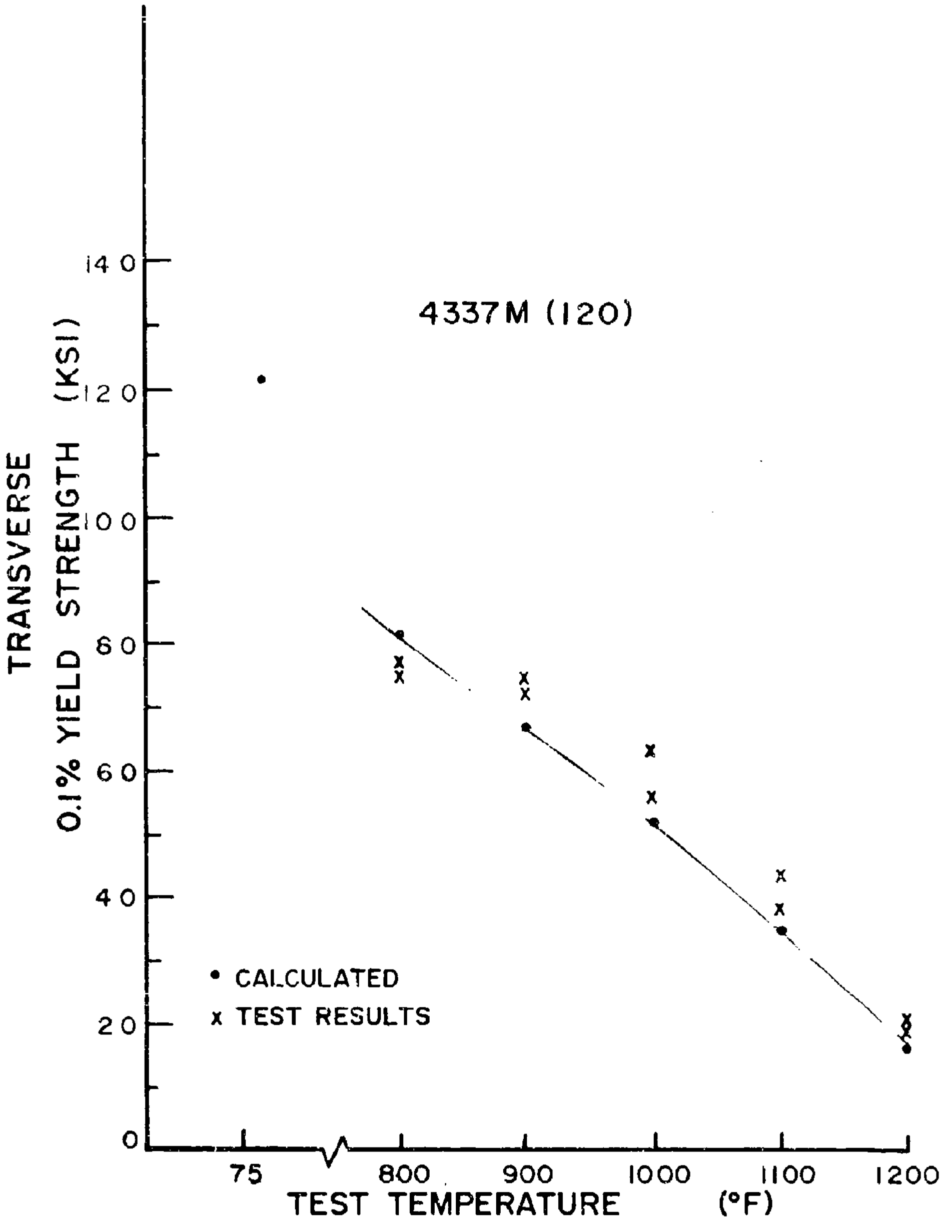
CALCULATED VS. ACTUAL YIELD STRENGTHS

FIG. 15



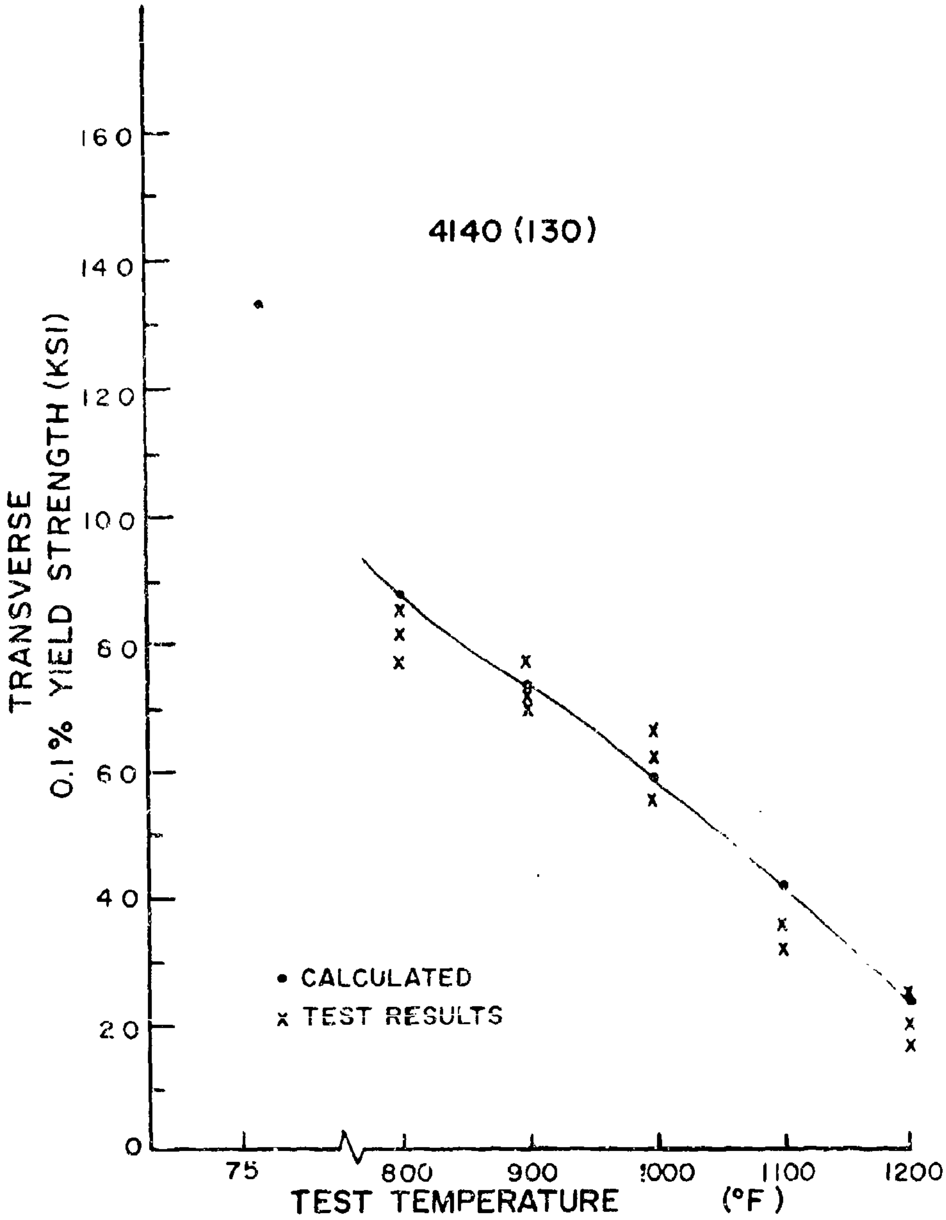
CALCULATED VS. ACTUAL YIELD STRENGTHS

FIG 16



CALCULATED VS. ACTUAL YIELD STRENGTHS

FIG. 17



CALCULATED VS. ACTUAL YIELD STRENGTHS

FIG 18

TABLE I

CHEMISTRY OF ALLOYS TESTED

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Al	Cu
AISI 4140	.40	.92	.014	.018	.27	-	.98	.18	.05	-
AISI 4337 Mod.	.38	.72	.007	.008	.30	1.83	.77	.35	-	.10
AISI 4337	.37	.70	.035	.040	.28	-.84	.80	.25	.05	-

TABLE II

HEAT TREATMENT USED ON ALLOYS TESTED

Alloy	Austentizing Temp.	Austentizing Time	Tempering Temp.	Time	Nominal YS (P.T.)
4337 M (170)	1550°F	1.5 hrs.*	950°F	2 hrs**	170 ksi
4337 M (155)	1550	1.5 *	1025	2 **	155
4337 M (120)	1550	1.5 *	1150	1.5 **	120
4140 (130)	1550	1.5 *	1100	1.5 **	130

* Oil Quench
** Water Quench

TABLE III

Tensile, Charpy Impact and Hardness Data on 4140 (130) Tempered at 1100°F

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	EL %	RA %	-40°F Cv* (ft-lbs)	Rc*
R.T.		151	137	133	8.6	29.4	15.5	30
R.T.		138	139	134	13.2	32.2	13.5	31
R.T.		150	130	127	12.8	30.4	14.8	30
R.T.		149	131	129	11.8	24.0	14.2	30
800	.08	124	92	84	17.5	44.9		
800	.08	124	90	81	16.1	42.4		
800	.25	118	93	86	13.6	43.9		
800	.25	114	91	85	17.5	51.6		
800	.50	112	90	84	17.0	50.2		
800	.50	112	90	84	15.7	51.2		
800	.75	112	88	80	15.4	47.0		
800	.75	113	90	84	13.2	42.0		
800	1	108	86	80	13.2	47.0	12.5	31
800	1	107	85	77	14.3	50.2	14.0	30
800	5	102	82	77	15.0	49.3	14.0	31
800	5	105	82	74	17.1	47.2	14.8	32
800	10	106	89	83	17.9	52.1	10.5	32
800	10	105	83	77	21.4	54.4	12.0	32
800	15	109	88	82	14.7	46.2	13.3	32
800	15	108	88	83	12.8	45.6	13.8	33
800	20	108	85	78	15.7	50.0	14.8	31

* Value obtained after exposure

Table III continued

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv* (ft-lb)	Rc*
800	20	105	82	77	16.8	51.4	11.0	31
800	25	103	80	73	18.3	52.3	11.3	30
800	25	112	93	87	17.2	46.9	12.5	31
800	30	103	94	90	19.0	54.4	12.5	31
	30	105	82	76	17.1	51.7	11.0	32
900°	.08	103	83	76	16.7	55.5		
900	.08	105	88	81	15.0	52.5		
900	.25	98	81	74	17.9	57.4		
900	.25	101	84	78	17.0	53.2		
900	.50	98	84	78	17.5	57.0		
900	.50	86	83	77	17.5	55.5		
900	.75	100	84	78	15.5	54.4		
900	.75	101	86	80	17.5	55.2		
900	1	96	81	77	14.7	54.6	12.0	31
900	1	90	79	73	17.8	53.4		
900	5	98	79	73	20.0	54.7	12.5	32
900	5	84	70	64	20.4	61.6	13.8	32
900	10	75	63	58	26.8	68.9	11.8	31
900	10	93	77	71	17.8	51.3		32
900	15	97	86	81	20.7	49.7	10.5	31
900	15	96	77	71	13.2	53.2	11.3	30
900	20	90	71	62	15.7	59.3	12.3	30
900	20	92	78	73	17.1	50.9	12.0	32
900	25	93	79	73	19.6	57.0	10.8	31

Table III continued

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0-2 YS (ksi)	0.1 (ksi)	El %	RA %	-40°F Cv (ft-lbs)	Rc
900	25	99	81	75	12.1	47.0	10.8	30
900	30	93	82	78	14.3	50.1	9.8	31
900	30	92	79	73	16.4	52.1	11.0	30
1000	.08	87	74	68	16.1	61.3		
1000	.08	86	76	70	20.8	68.0		
1000	.25	81	67	67	18.6	65.0		
1000	.25	83	72	67	18.6	63.7		
1000	.50	81	71	67	17.5	63.4		
1000	.50	82	73	68	14.3	61.6		
1000	1	79	68	63	17.5	64.0		
1000	1	85	74	69	16.4	63.0		
1000	1	70	53	47	25.4	65.0	11.5	31
1000	1	66	48	47	31.4	67.0	11.5	32
1000	5	74	67	63	20.0	61.0	10.8	30
1000	5	74	61	56	23.5	58.6		
1000	10	78	61	58	24.0	66.4	10.0	32
1000	10	70	55	47	22.8	63.6	13.5	31
1000	15	76	63	55	19.3	54.8	12.3	31
1000	15	59	55	31.4	66.0			
1000	20	64	46	39	45.7	68.9	14.3	30
1000	20	75	62	58	24.1	64.2	9.8	32
1000	25	76	63	57	2[illegible].1	62.7	10.0	29
1000	25	83	66	63	21.4	59.5		
1000	30	66	54	48	18.9	62.4	10.8	30
1000	30	73	60	52	20.8	63.7	10.3	31

Table III continued

Test Temp. (°F)	Exposure Time (Hrs)	UTS (ksi)	0.2 YS (ksi)	0.1 (ksi)	El %	RA %	-40°F Cv (ft-lbs)	Rc
1100	.08	64	42	36	24.0	68.9		
1100	.08	60	38	32	25.7	63.4		
1100	.25	56	41	34	27.5	68.0		
1100	.25	55	40	33	24.0	63.2		
1100	1	43	33	27	40.0	67.6	16.3	31
1100	1						16.5	30
1100	5	36	35	31	31.4	69.0	●10.5	28
1100	5	45	32	27	27.5	71.0	12.00	28
1100	10	61	32	27	32.2	74.8		
1100	10	55	47	34	20.8	71.3		
1100	15	49	37	31	53.5	72.0	14.8	28
1100	15	47	37	32	26.8	71.0	14.3	29
1100	25	44	39	37	42.1	77.6	17.8	28
1100	25	49	37	33	21.4	73.6	13.3	29
1200	.08	38	20	17	15.7	60.2		
1200	.08	33	20	18	32.1	59.1		
1200	.25	30	22	19	64.0	22		
1200	.25.	33	22	20	62.3	22		
1200	1	29	23	20	74.4	64.9	22.3	27
1200	1	33	22	19	25.0	71.6	24.0	26
1200	10	31	23	20	46.5	83.0	23.8	21
1200	10	27	25	22	35.4	76.8	23.5	21
1200	20	26	23	22	79.2	84.6	23.3	21
1200	20	31	30	28	24.0	72.8	21.5	22

Blank spaces denote data not taken

TABLE IV

Tensile, Charpy Impact and Hardness Data
on 4337M (170) at 950°F

TEST Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv*	Rc
RT		186	178	175	10.4	26.6	15.5	40
RT		188	179	177	12.5	37.4	14.0	41
RT		181	170	166	9.7	31.3	16.0	40
800	.08	150	126	117	10.4	33.6		
800	.08	153	130	121	15.4	50.2		
800	.25	149	123	114	15.4	52.9		
800	.25	145	123	114	13.2	47.4		
800	.5	140	119	109	10.7	36.3		
800	.5	141	120	111	14.7	49.0		
800	1	146	130	121	15.1	49.7	13.3	41
800	1	147	129	121	13.2	14.8		41
800	5	140	119	109	13.2	48.8	14.0	41
800	5	144	132	125	13.6	46.7	16.3	40
800	10	139	114	103	12.8	48.5	14.8	41
800	10	145	124	11[illegible]	14.3	44.8	14.5	41
800	15	143	121	112	10.7	39.2	14.8	41
800	15	128	110	103	12.8	50.1	14.3	41
800	20	140	125	1[illegible]8	1[illegible].6	47.4	14.0	40
800	20	142	120	113	13.6	52.1	14.0	41
800	25	142	134	132	14.0	47.8	13.5	41
800	25	142	131	127	11.4	36.2	16.3	40

* Values obtained after exposure

Table IV continued

Test Temp. (°F)	Exposure Time Hrs.	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv	Rc
900	.08	132	111	104	16.1	54.2		
900	.08	139	119	111	14.5	49.4		
900	.25	129	108	101	15.4	55.0		
900	.25	128	107	99	11.5	44.6		
900	.5		114	108	16.1	57.0		
900	.5	124	111	104	14.0	46.6		
900	.75	124	110	97	14.7	51.7		
900	.75	124	110	97	12.8	46.6		
900	1	124	107	98	16.8	50.6		
900	1	127	110	101	15.4	53.2		
900	1	125	109	9-	16.4	45.5	15.5	40
900	1	128	106	92	11.8	44.9		
900	5	124	112	106	12.2	29.5	14.3	40
900	5	126	107	97	14.0	50.2		
900	10	126	109	98	14.3	39.5	17.3	39
900	10	124	108	99	14.7	51.4	15.0	41
900	15	125	106	96	13.5	39.0	14.5	41
900	15	125	106	97	15.0	52.5	18.0	40
900	20	124	115	108	12.1	36.4	13.8	41
900	20	123	105	97	12.1	44.9	13.8	41
900	25	131	114	108	17.9	59.5	13.3	41
900	25	130	124	117	14.3	45.6	13.3	41
900	30	129	111	102	11.8	45.8	14.8	41
900	30	128	118	106	15.0	50.7		

Table IV continued

Test Temp. (°F)	Exposure Time Hrs.	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv	Rc
1000	.08	110	90	80	17.5	49.0		
1000	.08	111	90	80	18.6	50.2		
1000	.25	107	84	71	17.1	46.4		
1000	.25	90	70	63	17.5	48.3		
1000	.5	100	76	70	22.6	54.8		
1000	.5	94	72	63	20.4	46.2		
1000	.75	95	75	67	22.8	54.8		
1000	.75	95	77	70	22.6	55.5		
1000	1	102	84	75	16.1	52.1		
1000	1	102	85	76	14.7	48.3		
1000	1	101	59	48	19.3	52.4	16.8	40
1000	1						16.0	41
1000	5	94	75	64	24.2	59.2	23.5	37
1000	5	95	86	80	27.8	63.0		
1000	10	99	71	57	22.2	64.2	22.5	38
1000	10						28.0	37
1000	15	90	71	61	20.0	47.4	26.8	38
1000	15	89	78	71	25.0	57.4	26.3	38
1000	20	89	75	68	19.3	64.0	28.3	37
1000	20	88	74	65	32.2	63.3	30.0	36
1000	25	91	79	74	26.4	59.5	33.5	35
1000	25	90	77	71	23.6	60.4	33.5	36
1000	30	87	72	66	20.8	66.7	27.8	37
1000	30	88	75	69	22.8	63.4	30.3	36

Table IV continued

Test Temp. (°F)	Exposure Time Hrs.	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv	Rc
1100	.08	74	49	39	19.3	50.8		
1100	.08	70	47	39	23.2	50.6		
1100	.25	65	40	31	22.2	53.6		
1100	.25	63	38	30	29.0	58.0		
1100	.5	67	52	43	18.3	56.3		
1100	.5	71	49	40	22.6	63.5		
1100	1	54	36	32	22.8	62.6	35.8	35
1100	1	59	51	47	45.0	65.0	36.5	35
1100	5	55	36	30	30.0	67.3	32.3	34
1100	5	53	40	33	33.6	68.5	33.0	34
1100	10	50	37	31	34.3	71.5		
1100	10	61	37	32	34.4	79.6		
1100	25	55	44	39	27.1	74.5	31.3	33
1100	25	59	38	33	38.6	80.9	35.8	32
1200	.08	26	16	14	49.6	72.2		
1200	.08	32	15	12	58.6	67.8		
1200	.25	31	16	12	82.0	77.3		
1200	.25	31	16	14	51.8	68.6		
1200	1	40	18	16	48.5	84.6	45.5	30
1200	1	26	16	13	61.5	78.1	45.8	30
1200	10	25	16	13	56.0	81.4	43.8	24
1200	10	24	18	16	69.0	73.8	51.8	23
1200	20	24	16	13	35.0	81.8	47.3	20
1200	20	25	19	16	64.4	88.7	41.3	21

Blank spaces denote data not taken

TABLE V

Tensile, Charpy Impact and Hardness Data on 4337M (155) Tempered at 1025°F

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv*	Rc*
RT		167	161	157	12.1	39.7	29	37
RT		168	162	158	12.1	41.6	29	38
RT		170	159	155	10.7	36.3	28	38
RT		176	164	161	13.2	39.8	30	37
800	.08	139	117	110	13.2	44.9		
800	.08	142	118	110	14.3	47.2		
800	.25	138	115	107	12.5	42.3		
800	.25	141	119	112	14.7	51.4		
800	.50	137	115	107	15.4	54.4		
800	.50	137	117	112	14.3	49.8		
800	.75	136	114	107	12.1	43.6		
800	.75	137	117	110	13.2	45.8		
800	1	126	115	108	14.3	52.3	26.0	38
800	1	129	106	98	17.1	55.1	29.0	38
800	5	130	112	105	10.7	39.6	29.3	38
800	5	128	111	102	14.3	49.8	26.8	38
800	10	118		108			30.0	36
800	10	131	122	118	15.7	50.9	28.0	38
800	15	143	126	118	14.3	51.0	28.3	38
800	15						25.8	38
800	20	132	113	105	15.0	50.8	28.5	38

* Values obtained after exposure

Table V continued

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv*	Rc*
800	20	131	115	109	14.3	50.5	28.0	38
800	25	129	122	108	15.0	48.1	24.0	38
800	25	132	107	98	15.7	48.3		
800	30	133	118	114	15.7	52.5	29.8	37
800	30	126	117	113	14.7	53.2	28.3	38

Table V continued

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv	Rc
900	.08	125	108	100	13.2	53.6		
900	.08	128	109	101	12.5	46.4		
900	.25	122	105	98	13.2	52.1		
900	.25	124	107	100	15.7	54.8		
900	.50	127	109	101	13.6	51.4		
900	.50	122	111	104	15.4	57.4		
900	.75	119	101	94	12.8	48.6		
900	.75	123	107	101	15.4	54.6		
900	1	115	98	89	18.6	61.3	30.5	37
900	1	111	98	92	17.5	57.7	24.3	38
900	5	112	93	81	11.4	43.9	26.8	37
900	5	118	103	96	17.7	58.1		
900	10	117	103	95	17.9	62.0	30.0	37
900	10	116	103	96	17.8	48.9	26.3	38
900	15	112	99	94	17.1	56.3	27.0	38
900	15	116	101	95	16.1	58.6	26.8	39
900	20	113	104	97	17.8	57.4	28.5	38
900	20	117	97	89	15.7	56.6	29.8	38
900	25	116	102	96	15.0	52.1	26.8	38
900	25	121	102	96	13.6	54.4		
900	30	117	104	97	17.0	57.4	27.8	37
900	30	116	108	104	17.8	55.9	26.3	37

Table V continued

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv	Rc
1000	.08	108	92	83	17.9	61.3		
1000	.08	104	89	81	17.1	64.0		
1000	.25	107	91	85	16.1	60.6		
1000	.25	96	78	71	18.3	59.5		
1000	.50	98	82	76	20.1	58.5		
1000	.50	102	84	77	16.1	56.6		
1000	.75	105	94	86	13.2	49.4		
1000	.75	54	44	42	23.2	74.0		
1000	1	91	78	71	22.8	62.7	29.8	36
1000	1	98	84	77	15.0	54.4	27.3	37
1000	5	87	67	54	20.7	58.7	31.5	
1000	5	91	79	73	24.3	62.0		
1000	10	85	80	78	21.4	58.5	28.7	36
1000	10	94	82	75	18.6	63.0	31.0	36
1000	15	89	79	72	20.7	64.0	26.8	37
1000	15	89	79	74	22.8	58.6	28.0	36
1000	20	88	73	66	18.6	65.0	35.8	35
1000	20	91	80	73	21.4	64.4	34.3	35
1000	25	85	66	59	20.0	61.6	28.8	36
1000	25	87	79	74	34.2	61.6	32.0	
1000	30	86	73	65	22.1	64.6	33.0	37
1000	30						27.8	38

Table V continued

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv	Rc
1100	.08	74	51	45	15.0	44.9		
1100	.08	69	43	41	25.4	53.6		
1100	.25	60	42	36	18.6	54.0		
1100	.25	59	35	31	22.8	60.9		
1100	1	55	43	38	36.4	66.6	36.5	35
1100	1	54	40	33	34.3	67.2	37.5	34
1100	5	53	40	33	33.6	68.5	34.5	35
1100	5	57	38	32	38.0	69.8	37.3	34
1100	10	54	43	34	33.6	65.9	38.0	34
1100	10	41	36	35	32.2	68.9	37.3	34
1100	25	51	36	28	35.7	69.0	39.0	33
1100	25						42.5	32

Table V continued

Test Temp. (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %	-40°F Cv	Rc
1200	.08	36	21	18	26.0	66.3		
1200	.08	37	23	19	26.8	63.0		
1200	.25	34	20	17	26.4	67.0		
1200	.25	34	17	14	55.0	77.6		
1200	1	27	19	14	57.8	73.9	47.3	27
1200	1	24	18	17	60.5	81.6	45.8	20
1200	10	26	18	16	62.9	81.5	54.8	23
1200	10	33	27	24	33.6	83.9	56.0	22
1200	20	25	16	12	39.3	82.0	52.0	21
1200	20	31	13	11	69.5	85.7	44.8	22

Blank spaces denota data not taken.

TABLE VI

Tensile Data On
4337M (120) Tempered at 1100°F

Test Temp (°F)	Exposure Time (Hrs.)	UTS (ksi)	0.2 YS (ksi)	0.1 YS (ksi)	El %	RA %
RT		138	123	122	12.5	36.1
RT		139	124	123	13.2	42.8
800	1	106	77	75	19.7	60.2
800	1	107	84	77	17.5	58.8
900	.25	97	79	73	22.2	63.0
900	.25	96	81	75	21.4	64.5
1000	1	78	62	56	17.9	56.6
1000	1	81	66	64	24.0	70.1
1100	1	61	46	39	29.6	75.9
1100	1	63	51	44	25.4	66.7
1200	1	37	25	21	47.1	79.6
1200	1	40	25	21	33.2	76.5

TABLE VII

0.1 YS at Test Temperature (ksi)

Test Temp.	4337M (170) C = .432T Act.*	Calc.	4337M (155) C = .392T Act.*	Calc.	4337M (120) C = .304T Act.*	Calc.	4140 (130) C = .330T Act.*	Calc.
			IT = 800°F					
R.T.	172		157		122		133	
800	115	115	109	105	76	81	84	[illegible]
900	102	96	99	87	74	67	76	74
1000	72	74	75	67	59	52	67	57
1100	40	49	36	45	42	35	32	38
1200	15	23	18	21	21	16	20	19

* The average of two or more tests